SOIL CONSERVATION

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A Foreword to THIS ISSUE

by *W. C. Lowdermilk*[1]

THE Nation has paid heavily during the last 9 months in relieving the distress and repairing in small part the damage wrought by a major drought and a record-breaking flood. Soils are wasting at perilous rates from thousands of sloping fields. Duststorms have left disease and destruction behind them. Silting of streams and reservoirs has become an acute problem.

REHABILITATION of the land constitutes a vital national cause, the success of which calls for the combined effort of agencies concerned with agriculture, forest industry, education, flood control, and national planning. Prompt and effective action is necessary to conserve our soil and water wealth. Accomplishment of the objective requires that each farm or tract needing treatment be managed in the interests of a permanent and sustained agriculture.

RESEARCH in soil conservation must explore the nature, causes, and effects of soil and water wastage under necessary agricultural pursuits. It must determine and test fundamental and practical means of preventing undue wastage and the feasible restoration of resources incident to sustained and needful land use. It must bring to bear upon the problems involved several fields of science and practice, and call into cooperation the agencies concerned with these special fields. It must plan and carry out, in cooperation with State experiment stations and other appropriate scientific and technical agencies, a program of research in erosion and silt control, soil and water conservation, and determine their suitability to serve the progressive needs of agriculture. In fulfilling these functions, research must serve the present and future needs of the farmers of the Nation, and contribute to the sustained use of land and water resources by furnishing to field operations of this Service and of other agencies tested and reliable information.

ACOORDINATED attack is the policy of the Soil Conservation Service in its field operations. So is it equally the policy in its research to bring to bear upon the complex phenomena of erosion and its control the necessary fields of science and practice for solutions to the multitude of problems which are arising in the search for a permanent agriculture on the Nation's farm and pasture lands.

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THE RESEARCH PROGRAM of the Section of Climatic and Physiographic Research

By C. W. Thornthwaite

Head of the Section of Climatic and Physiographic Research, Division of Research

AGRICULTURAL research is of three types: (1) experimental, (2) observational field and laboratory investigations, and (3) library and archive study. Although controlled experimentation is the most familiar type of methodology to agricultural research workers, the other types have contributed fundamental advances to agricultural knowledge. Modern soil science, for example, is a product of intelligent observation of the characteristics and distribution of soils, and methods for control of insect pests and crop diseases arise frequently from careful field observation. Historical library studies are important in all branches of agricultural research.

All three types of research are employed in the Research Division of the Soil Conservation Service. The work of the Section of Climatic and Physiographic Research, however, involves only the observational and library methods. It amplifies and supplements the results of controlled experimentation by providing an historical perspective and by supplying means for the extrapolation from experimental results beyond the limited areas within which the experiments are conducted.

Erosion History

Through research in the history of erosion it will be possible in a comparatively short time to assemble the results of past experience of individual farmers in erosion control and thereby determine the point at which experimentation should begin and indicate the direction for future research. By so doing some of the preliminary stages of experimentation might be eliminated and the final results checked against the experience of practical farmers. For example, it has been found that Bermuda grass, which was introduced into Oklahoma during the last decade of the nineteenth century, spread rapidly westward and its position as an erosion resisting plant seemed firmly established by 1908. Then came the cold dry years of 1909–10, during which Bermuda was killed out throughout the entire western half of the State. Recognition of this early farmer experience should make unnecessary further planting of Bermuda in the area where it proved to be unsuited. Detailed analysis of the climatic risks will make it possible to determine the limits of practical Bermuda culture not only in Oklahoma but also in the neighboring States. Beyond the limits thus established further experimentation on Bermuda grass for erosion control is useless unless hardier varieties can be developed.

Similarly, in all sections of our country erosion has followed closely upon settlement, and in each section the more progressive farmers recognized the evil and developed farm practices adapted to their individual erosion problems. In a recent publication entitled "Early Erosion Control Practices in Virginia", (U. S. D. A. Misc. Pub. No. 256, 1937), A. R. Hall has shown the large amount of valuable information for Virginia, the oldest of the States—information extending over a period of more than a century and a half.[1] As population moved westward, farmers at first practiced those control measures which had proved successful somewhere in the East. If these failed they were either discarded or modified to meet the new conditions, and new bodies of literature on the subject developed. For Oklahoma, the youngest agricultural State, local farm journals from 1890 to the present contain an invaluable source of information on erosion control.[2] Without doubt, similar material is available for all parts of the country. Experimentation is necessarily limited to selected stations and to the period of time covered by the work. The experience of farmers knows no such limits but includes all types of climatic conditions to which a region is subject and covers a wide range of physical and agricultural conditions and long periods of time. It extends beyond the limits of our own country. Types of climate are repeated in various parts of the world, and all sections of our country now suffering from erosion have their foreign counterpart. It is to these selected areas that we must look for new erosion-resisting crops, and much exploration in this field can be performed with little expense through library research.

[1] A. R. Hall: The Problem of Soil Erosion in Ante-Bellum Virginia, p. 239 this issue.

[2] Angus McDonald: Erosion by Wind and Water in Oklahoma, p. 233, this issue.

THE RESEARCH PROGRAM of the Section of Climatic and Physiographic Research

In some foreign regions soil conditions have been maintained under cultivation for long periods of years. The means by which this has been accomplished has a direct bearing on the erosion-control problem in equivalent regions in the United States. Other regions have been abandoned because of erosion. Such is the case in the Ordos desert of North China, a region with a climate similar to that of the northern Great Plains. Extensive areas in North Africa and Assyria, which once produced abundant crops, have been converted into useless waste although the climate has remained unchanged. Similar changes are now occurring not only in this country but also in other new countries such as the Union of South Africa. What were the specific causes of such changes in the past and what conditions prevailed during the periods of transition? Such information is essential for the diagnosis of the stage of erosion here and for the development of long range plans for erosion control.

Physiography

For effective application of the knowledge of erosion control gained from past experience and current experimentation it is necessary to have a detailed and comprehensive understanding of the nature of various erosion processes, their effects on different soil types, and their varied manifestations under different conditions of land use. Erosion is a geologic or physiographic process caused by such natural forces as running water, wind, and frost. The importance of these forces varies according to geology, farm practices, climatic conditions, and other factors. Some soils are known to be particularly susceptible to sheet erosion and others to gullying. Under proper vegetative cover these soils may be completely protected from sheet erosion and gullying but may experience gravity movements of soil masses.

The nature of erosion is best determined by careful observation while it is taking place, for example in typical gullies or on washed fields during and after rains. It is essential that erosion processes be observed in action during rains and melting of snow, during freezing and thawing, during dry weather as well as wet, in short, under all possible conditions of climate. The effect of storms of various intensities differs according to land use, slope, underlying bed rock, soil type, and the particular soil horizon exposed to erosion, whether topsoil, subsoil, or parent material.

By field study in selected areas throughout the country the relations of erosion hazard to soil and rock types and to climatic conditions can be worked out and the regional pattern of erosion types can be determined.

A thorough understanding of the mode of development and life history of erosion forms should reduce the possibility of applying incorrect and unsatisfactory control methods, and should aid in the development of a technique of control by strategy rather than by force—working with the laws of nature rather than against them.[3] Only with a full knowledge of erosion processes and their relation to agriculture can an adequate program of control measures be devised.

Climate

Prerequisite to a general application of the knowledge of erosion processes in relation to soil, rock type, and agricultural practices is the detailed analysis of climate. Under given geologic conditions the erosion processes and effective means for controlling them will be similar throughout an entire climatic region. Thus the delimitation of climatic regions is necessary to the determination of effective limits of various erosion practices. Within a climatic region the hazard from water erosion, and consequently the designs for erosion-control structures, can be determined only through knowledge of the frequency of rains of specific intensities. The life-history analysis of rainstorms, now in progress, is yielding results of great importance concerning the behavior of storms of different types and the amount and intensity of rainfall which may be expected through the area across which the storm passes.[4] It has been found that there are two distinct types of rainstorms, each with characteristic size, shape, internal structure, and behavior patterns. The first type is of rather short duration (1 to 3 hours), covers from 700 to 900 square miles, and has centers

[3] C. F. Stewart Sharpe, "Brushing Out" the Banks of Streams, p. 221 this issue; D. Hoye Eargle, When is a Gully Stable? p. 223; and H. A. Ireland, Rotation of Gully Heads, p. 228.

[4] Leonard B. Corwin, Sampling the Weather at the Oklahoma Climatic Research Center, p. 237, this issue.

of high rainfall intensity not infrequently up to rates of 5 inches an hour. The second type is of wide areal extent (sometimes as much as 400,000 square miles), of long duration, is gentle and continuous, and contributes a large amount of water. The first type of rainfall is most significant in the production of gully and sheet erosion as well as occasional local floods. The second type is significant in stimulating mass or gravity movements of soil, such as slumping and caving of gully sides and heads, and is invariably the cause of major floods.[5] Not infrequently in connection with the widespread, continuous type of rain, local areas will experience for short periods the high intensities characteristic of the first type. Of great significance is the determination in the field of the relation of the various erosion processes to rainfall types.

Wind erosion has been found to be less a function of velocity than of turbulence of the air. In turbulent air sometimes oval-shaped areas and sometimes channels of high velocity parallel to the wind direction develop on the surface. These channels or oval-shaped areas seem to explain why some fields may suffer greatly from wind erosion and adjoining fields may remain practically undamaged, even though soils and land use appear to be identical.

Frost action has a profound influence on a type of soil wastage provisionally called mulching. Alternate freeze and thaw, and the associated development of frost crystals or needles prepares the surface for sheet-wash and also directly causes considerable down-slope movement of the soil. A map of the United States showing the annual number of freeze and thaw periods tends to show the localization of this erosion process.[6]

Ecology

It is recognized that plants are ultimately both the most effective and the cheapest method of controlling erosion. At the same time, the plant cover affords the best means available for diagnosing the degree of erosion that has occurred or the stage of recovery. For example, in pastures a relative increase in certain species of plants is the first indication of overgrazing and should serve as a danger sign of subsequent erosion. Conversely, recovery and stabilization are heralded by gradual changes in the plant cover—changes which follow definite sequences under different soil and climatic conditions. Natural succession, for example, will differ at the mouth and head of a gully or on the A and B soil horizons. A thorough understanding of natural regeneration would in many places make possible a "short circuiting" of the normal processes of recovery. This principle has been successfully applied in other countries and the possibility of similar work in this country should be investigated.

Ecological research also includes the mapping of plant distribution and the delimitation of vegetation zones.[7] Because it reflects the interrelation of environmental factors, each vegetation zone will throughout its extent have essentially similar problems of erosion and erosion control. Consequently, such zonation will provide a basis for wider application of results obtained by experiment stations. Ecology is no longer a purely academic study but one of the most practical tools which can be applied in the rebuilding of eroded soils.

Although erosion on farm lands is induced by man and of a vastly accelerated type, nature has supplied means of control even for the most malignant forms. It remains for us to discover what nature has provided. Sometimes this involves the manipulation of the very forces which produced the erosion. When enough is known about the processes of gully formation the same water which caused the gully may be used to fill it up and stabilize it. Plants exist which will grow in virtually all types of environment. Even on the moving sand dunes of the North Pacific coast, Holland or European beach grass will thrive. It may be covered to depths of over 20 inches with blowing sand without killing. But as soon as the sand ceases to be mobile and begins to accumulate organic matter, Holland grass dies out and is succeeded by other species. This means that new species of plants must be discovered to meet each of the progressive stages of recovery not only on

(Continued on p. 236)

[5] B. Holtman and K. Clarke-Hafstad, Changes in Atmospheric Circulation Result in Floods, to appear in the May issue.

[6] H. Bates Brown, The Slope Factors in Soil Erosion, p. 240, this issue.

[7] J. E. Englemann, Ecologic Relationships in the Oklahoma Climatic Research Center, p. 235, this issue.

"Brushing Out" the BANKS of STREAMS

By C. F. Stewart Sharpe[1]

Cutting of brush and trees from this segment has left a broad, clear flood channel which rushes the waters to the sea. North Tyger River, in flood, near crossing of Reidville-Spartanburg highway.

Same site as above during normal river stage, showing brushed-out flood channel and stumps of 20- to 30-year-old trees. Other trees cut nearby were over 60 years of age.

ALONG many of the creeks and smaller rivers of the country one may see today denuded banks bearing fresh scars of the ax, brush hook, and fire. Such are the signs of local "drainage" and "mosquito-control" projects on which vast sums are being expended to speed the removal of flood waters by clearing or "brushing out" the flood channels. The effects of such clearing are much more intricate than is generally realized and should be given full consideration before this work is carried further. Temporary improvement of flood conditions and sanitation may be attained in the areas treated but what of the people, lands, and cities downstream? How much will floods on the major rivers be increased by rushing the water down the tributaries? Trees cut along some of the streams cannot be replaced for 50 years and by that time what will erosion have done to the banks; how much sand will have been deposited on arable lands farther down the river? Potential destruction of valuable bottom lands makes this practice of brushing out demand investigation and observation by the Soil Conservation Service.

The behavior of a stream heavily loaded with sand and silt differs greatly from that of a flume carrying clear water and any upsetting of the delicate balance of the stream mechanism will be reflected by compensatory changes, often of a serious nature, both above and

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Sand flats on bottom lands along a creek which has been partially brushed out. During flood stage the entire flat at the right is inundated. Fair Forest Creek, 6½ miles southeast of Spartanburg, S. C.

Due to thick vegetation along the banks, flood waters on this small river move rapidly only in the normal channel. North Tyger River, in flood, 8 miles west of Spartanburg, S. C.

This valley, as described by the author, was formerly good farm land, but lateral swinging of the stream after the farmer cleared its banks of brush and trees, 36 years ago, made it suitable only for pasture and timber. Seven miles southeast of Spartanburg, S. C.

below. It is therefore important that projects involving alteration of natural conditions along a stream be considered throughly from all points of view and be planned with regard to their effect on the entire drainage instead of on a small artificial unit such as a county, township, or individual farm.

A Farmer's Experiment

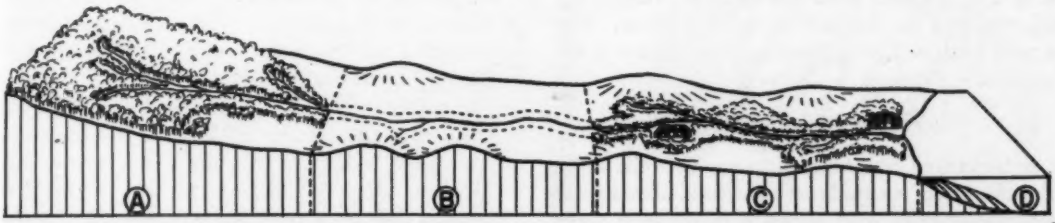
Some 36 years ago a farmer in the eastern part of Spartanburg County, S. C., decided that the land bordering a small stream flowing through his property would be improved if there were fewer trees along the banks to shade his crops and interfere with cultivation. The walls of the valley sloped in a gentle V-shaped profile and the stream flowed on a narrow valley flat, part of which was used for garden crops. The energetic farmer removed the brush and all but a few of the trees from along the stream but, unfortunately for him, cutting of the vegetation weakened the stream's banks. Caving and scouring followed and soon great bends and meanders were eating their way into his fields. Smooth slopes that once bordered the stream were cut away leaving cliffs 20 feet high and sand-covered flats.

Widening of the stream's flood-plain reduced the length of gullies and rills which drained the valley slopes and the general steepening of gradients resulted in deeper cutting of gullies into the hillside. The slopes of this little valley are now so dissected that they are suitable only for pasture and the excessive depth of the gullies makes the area hazardous for even that use. Accelerated stream erosion on this one farm has meant greater flooding and deposition of sand and silt on the lands farther down the valley. The owner fully realizes the mistake that was made and is quite ready to tell you, should you inquire, that brushing out the banks of his stream had been "a very poor idea!"

Many Local Projects

This story will be repeated on many other streams if local programs of brushing out continue. Most community drainage projects are on a somewhat larger scale and involve stretches miles in length—often the extent of the stream within a single county. A typical stream treated in this work is 20 to 40 feet wide, 3 to 10 feet deep, muddy, and flows in a rather broad valley with a narrow discontinuous flood plain. Weeds, shrubs, seedlings, and full-grown trees line its course. Cultivated fields and pasture lands lie along the margins of the flood plain and extend up the valley sides.

During high water the valley bottom is heavily inundated causing damage to crops, roads, bridges, and other valley-bottom structures. In order to reduce flood crests, by passing water on downstream more rapidly, bushes and trees are cut from the stream banks and from a belt 25 to 40 feet wide on both sides of the normal channel. The cuttings are burned or carried away leaving the ground practically bare. If

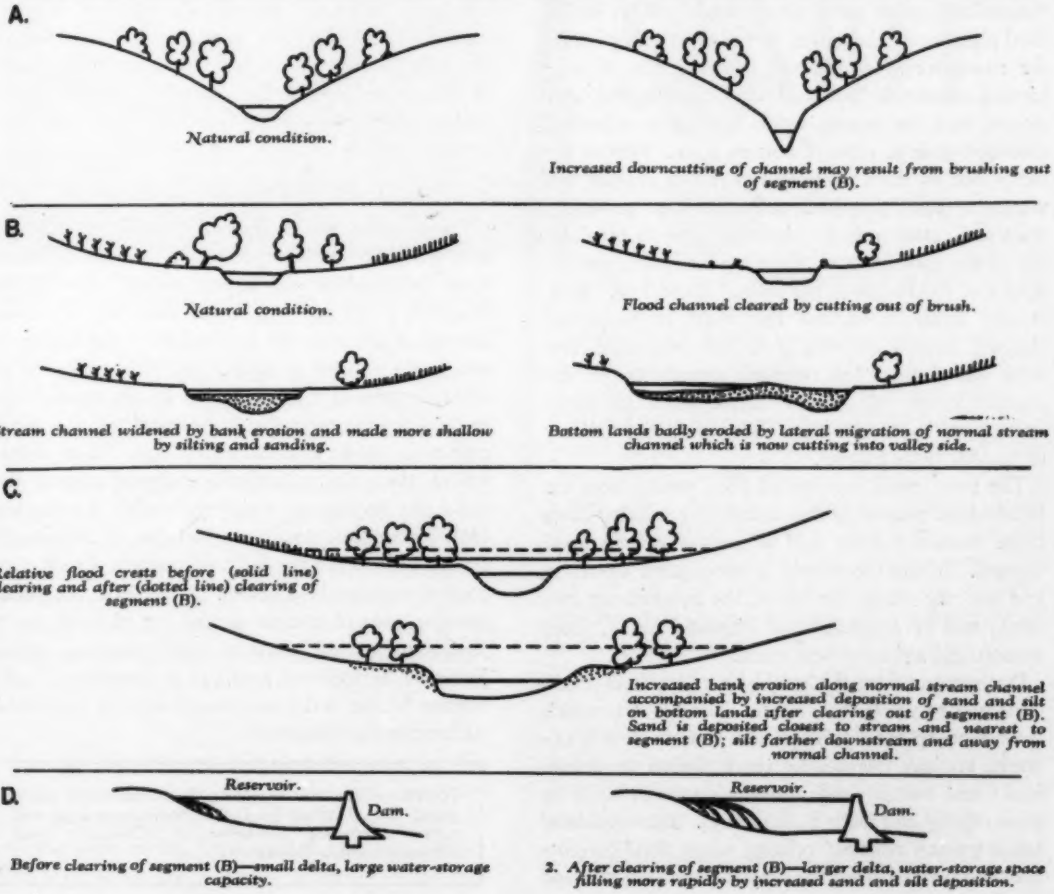


(A) Upstream segment.—Removal of vegetation along stream in segment (B) may cause accelerated downcutting of channel extending up into headwaters and tributaries, resulting in general steepening of slopes and increased rilling, sheet erosion, and soil creep.

(B) Brushed-out segment.—Removal of vegetation from stream banks allows more rapid drainage of flood waters, reducing crest heights and duration of floods but causing accelerated erosion of bottom lands due to increased lateral migration of stream associated with greater undercutting, slumping, and caving of banks; increased velocity during floods; increased scour and soil removal on bottom lands resulting in larger sand and silt load.

(C) Downstream segment.—More rapid receipt of flood waters from upstream produces higher crest stages, increased bank erosion of normal channel, and increased sanding of bottom lands due to retardation of currents by vegetation in flood channel.

(D) Mouth.—Increased sediment load from upstream causes greater deposition in deltas, bars, and spits, obstructing navigation and flood channels and gradually filling reservoirs and lakes.


A.
Natural condition.
Increased downcutting of channel may result from brushing out of segment (B).
B.
Natural condition.
Flood channel cleared by cutting out of brush.
Stream channel widened by bank erosion and made more shallow by silting and sanding.
Bottom lands badly eroded by lateral migration of normal stream channel which is now cutting into valley side.
C.
Relative flood crests before (solid line) clearing and after (dotted line) clearing of segment (B).
Increased bank erosion along normal stream channel accompanied by increased deposition of sand and silt on bottom lands after clearing out of segment (B). Sand is deposited closest to stream and nearest to segment (B); silt farther downstream and away from normal channel.
D.
Reservoir.
Dam.
Reservoir.
Dam.

1. Before clearing of segment (B)—small delta, large water-storage capacity.

2. After clearing of segment (B)—larger delta, water-storage space filling more rapidly by increased sand and silt deposition.

the roots on the cleared area decay before additional growths have time to develop, marked changes in the channel are likely to occur. In any case the removal of obstructing vegetation from the flood channel will subject it to greater scour and correlated changes on other parts of the drainage are likely to follow. The general result will be an increase in the activity of the soil-erosion processes.

Increased Channel Erosion

In the cleared, or brushed-out, segment of the valley the absence of vegetative obstructions allows more rapid drainage of flood waters with resulting lower flood crests and shorter duration of high water. The advocates of "brushing out" claim that there would be less opportunity for breeding of mosquitoes and other pests, so malaria would be less common. In the long run, however, the effect would be negligible. In the absence of systematic patrol and oiling the numerous stagnant pools which would remain in the flood plain would themselves serve as breeding grounds for mosquitoes. In addition, clearing out of soil-binding vegetation facilitates scouring, slumping, and caving, and the stream tends to migrate sideward endangering large areas of bottom lands. Higher velocity due to freer movement of floods enables the waters to carry a greater sediment load, providing more and better tools for abrasion. Due to brushing out of the flood channel, there is usually less concentration of flood scour in the normal stream bed. Bank erosion tends to increase the width of the normal channel, thereby allowing it to carry the same flow with less depth. The resulting aggradation in the channel leaves only shallow banks which are easily overtopped by flood waters. More frequent flooding of bottom lands follows.

The more rapid drainage of flood waters from the brushed-out portion of the stream may in other cases cause increased scour and deepening of the flood channel. If this deepening is propagated upstream and into the tributaries above, the brushed-out area slopes will be steepened and increased rilling, sheet erosion, and soil creep will result.

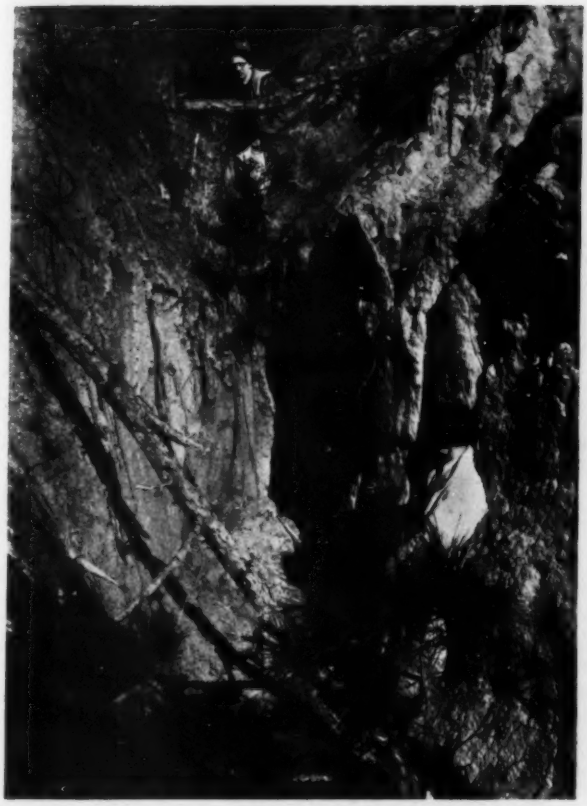
Downstream from the brushed-out area flood conditions will be worse than before. Flood waters which have been speeded through the cleared stretch upstream are here retarded by vegetation on the stream banks and bottom lands, causing floods to build up more rapidly and reach higher crests. Increased head tends toward increased velocity where flood currents are concentrated along the normal stream channel and erosion of banks is accelerated. Outside of the normal channel, however, the flood waters move but slowly. Most of their transporting power is lost and much of the silt and sand carried down from the brushed-out area is dropped. Silt deposition may not be detrimental to agriculture, but sand accumulation is responsible for the destruction of extensive areas of valuable bottom land.

At the mouth of the stream its flood waters and the remainder of its transported load are poured into a larger river or body of standing water. Here again the effects of the brushing out are felt. If the flood crests of the tributaries are synchronized a major flood is produced on the trunk stream. If, on the other hand, only one tributary is in flood its transported load tends to be deposited at the juncture with the more sluggish main river. The sediment reduces the flood capacity of the major stream, obstructs navigation channels, and makes the water less fit for industrial or sanitary uses. In lakes and reservoirs it accelerates delta building and general silting, which may seriously curtail or eliminate storage capacity for power or water-supply purposes, as has been shown by the Section of Hydrodynamic Research of the Soil Conservation Service.

Careful Planning Needed

These various effects indicate how human interference with the normal regimen of a river may produce many unlooked-for and serious results. (See "Little Waters", p. 27 and 39.) Local alteration of a river channel affects areas far removed from the locality in which the change is made. For this reason it is highly unwise that any program for the control of a through-flowing river should be restricted to a single county or other small arbitrary unit. Plans should include the entire watershed and should consider also the major drainage to which the project is tributary. Only by the most careful consideration of competently trained experts can the full consequences of such river-control measures be foreseen. There have been innumerable cases of streams getting out of hand due to ill-advised control measures with resulting serious losses to agricultural land. It is therefore of vital interest to the Soil Conservation Service to forestall such expensive blunders.

NOTE.—*Climatic maps in this issue were compiled and drafted by J. C. Owen, assistant soil conservationist, Division of Climatic and Physiographic Research.*



A "knick" about 9 feet high, advancing headward into a partially stabilized gully in Fairfield County, S. C.

When is a GULLY STABLE?

by D. Hoye Eargle[1]

IN MANY of the older agricultural regions of eastern United States there are hillsides, now covered with a thick second growth of forest vegetation, which were once riddled with active gullies. While such gullies bear witness of destructive agricultural practices of the past, their activity has ceased and they are commonly regarded as stable. Without the interference of man, they might remain stable but, if the natural drainage is altered or if the run-off of adjacent fields is increased by the removal of the absorbent topsoil, the activity may be resumed and a new cycle of erosion introduced.

Gullying Resumed

Many of the gullies, once healed, have resumed their latent activity and are again cutting both headwards and downwards. The vegetation is being removed and the slope of the gully walls is becoming steeper. This is especially characteristic in regions where resistant bed rock does not immediately underlie the surface. Those who would heal gullies artificially—by building check dams or by sloping the gully walls and then planting to vegetation—should first understand those forces which initiate renewed gully cutting.

About 1802 Playfair of the University of Edinburgh stated the law that all streams join at accordant levels. The corollary of this principle is also true: when the trunk stream becomes lowered all tributary streams tend to adjust themselves to that level. This principle applies not only to major drainage systems but also to the more minute features of the landscape, whether they be gully systems, terrace drains, or rills in sheetwashed fields.

The Knickpoint

Detailed mapping and continued observations of gullies in Spartanburg County, S. C., have shown that Playfair's law and its corollary are amply illustrated by the downward cutting and headward ad-

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vancement of gullies and by the initiation of new cycles of erosion when the levels of the master streams are lowered. As the lowering proceeds, the tributaries cut faster to keep pace with it. A steepening of the gradient near the mouth of the gully results. This migrates upstream as either a rapid or a fall. Such a step moving up a stream profile is known in the geological literature as a "knick" or "knickpoint."

If layers of unequal resistance to erosion exist in the soil or parent material, or if a mat of roots covers the channel of the gully, the "knick" is usually vertical or overhanging. In these cases the more resistant soil, rock, or vegetable matter holds up the top of the step and a cave may develop in the less resistant material beneath. The headward advancement of this step, as erosion continues, is accomplished chiefly by repeated breaking off of the lip and the caving in of the sod and trees when the old gully floor is undermined. If the material is homogeneous, or if little vegetation is present to toughen the gully floor, the "knick" is likely to be less abrupt or even a series of small steps.

How Base Level Is Lowered

The downcutting of a master stream or of one of the tributaries may be caused by an increase in volume of water flowing through it. This may be due to the rearrangment of the natural drainage by terracing or road drains, the breaking over of former terraces, or the removal of the absorbent topsoil from adjacent agricultural lands. If an "erosion pavement" [2] has developed as a result of sheetwash on lands with a tight or stony subsoil, the run-off is particularly rapid.

The lowering of the base level may also be caused by forces originating downstream. The clearing of valley lands below the gully system increases abrasion by the stream. It may then cut through a resistant channel floor to undermine it by sapping and caving of the weaker material beneath. Field observations indicate that this is one of the most frequent causes of renewed gully cutting.[3]

The Knick Advances

Two conspicuous illustrations of the conditions accompanying the destruction of all the stabilized features of gullies have been studied and mapped in Spartanburg County, S. C. In a gully on the farm of Fletcher Layton, 11 miles south of Spartanburg, a "knick" or step, now about 4 feet high, is advancing headward rapidly and in the process is clearing out trees as much as 33 years old and 10 inches in diameter. During the heavy rains of October 16 and 17, 1936, the "knick" advanced about 10 feet headward. In the area below, the average width increased from 15 to about 25 feet, causing the banks of the gully to cave in and uprooting many trees. The run-off from each successive storm drains through the gully, sweeps out the material which has caved into it, and advances the "knick" farther into the stabilized area.

Available evidence indicates that the cause of the rapid deepening of this gully is an increased flow of water into one tributary of the gully system. On the catchment basin of that tributary almost all of the topsoil has been removed, and during rains the water flows over a resistant clayey subsoil. In addition, several terraces have broken, which has increased the drainage area considerably. The increased run-off of the tributary has deepened the main gully below the junction and has produced a sharp "knick" which is migrating up the main gully channel.

Additional Water Accelerates Cutting

The second example occurs on a farm 3 miles southeast of Spartanburg. An extensive gully system in this neighborhood remained stable from about 1880 until some 15 years ago. Shortly thereafter more water was added to one of the tributary channels through a highway ditch and a terrace outlet. This channel has now cut downward 10 or 12 feet into the friable, parent soil-material and has caused "knicks" to progress up all of the other tributaries. Accelerated cutting has so deepened the active tributary channel that it has now become the master stream and the original master stream is but its tributary, flowing at a level about 7 feet above the other and emptying into it over a series of waterfalls and cascades.

Watershed Must Be Protected

It is evident that the "stability" of a gully may be described more accurately as "dormancy." To prevent rejuvenation or the renewal of excessive cutting, the watershed of the gully must be protected. This may be accomplished by cultivation practices designed to prevent excessive run-off, by revegetation, or by building up the organic content of the soil. The valley below must also be protected in order to prevent the stream from lowering its present base level. An increase in the water supply in any part of the drainage system beyond its normal capacity is therefore a potential source of danger.

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[2] See W. C. Lowdermilk, Agricultural Land-Use and Flood Control, occas. publications of the A. A. A. S., no. 3, October 1936, fig. 14, p. 26.

[3] See C. F. S. Sharpe, "Brushing-out" the Banks of Streams, p. 221

A gully 3 miles southeast of Spartanburg, S. C., recently redeepened about 12 feet below its former stabilized level. The dead tree is a remnant of the thick growth which formerly covered the gully bottoms.

"Erosion pavement" increases run-off and accelerates the down-cutting of streams below. A large, deep gully has formed below this shallow one because of increased run-off.

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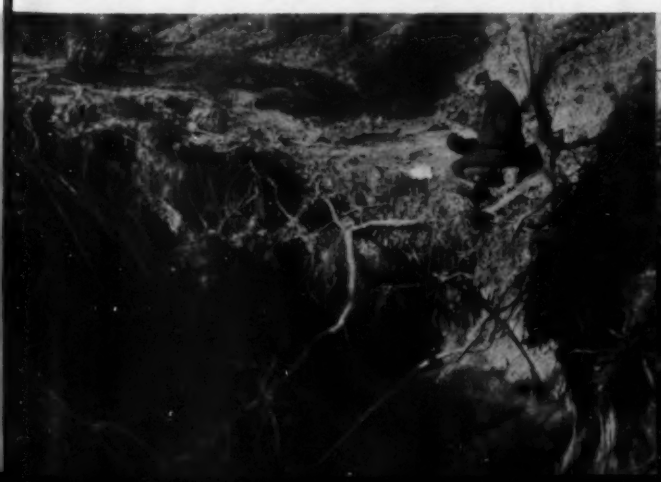
Therefore, in answer to the question "When is a gully stable?", one may say that a gully is stable, not when the walls and head have ceased advancing, nor when the channel of the gully has ceased cutting downward and is filled with growing vegetation, but only when all precautions have been taken to prevent renewed cutting and the consequent introduction of a new cycle of erosion.

(Page 227)

The pictures immediately above and below show how the clearing of vegetation in valley lands may cause serious stream erosion, causing "knicks" to progress up older gullies, as on this farm 8 miles south of Spartanburg, S. C.

Tree roots retard the advance of a "knick" in a gully bottom by forming a protecting mat over the friable soil material.



ROTATION OF GULLY HEADS

A New Conservation Practice for Gully Control [1]

By H. A. Ireland [2]

THE CHIEF objective in gully prevention and control is to conduct surface water to lower levels in such a manner that soil is not removed. Ideally this would involve the prevention of any concentration of water on any part of the surface. Practically, water concentration cannot be prevented where terraces and artificial drainage channels are used in erosion control. In certain situations, where gullies already exist, they may be stabilized by directing the surface run-off successively into several different heads, creating new heads if they are not already available.

A Simple Control Measure

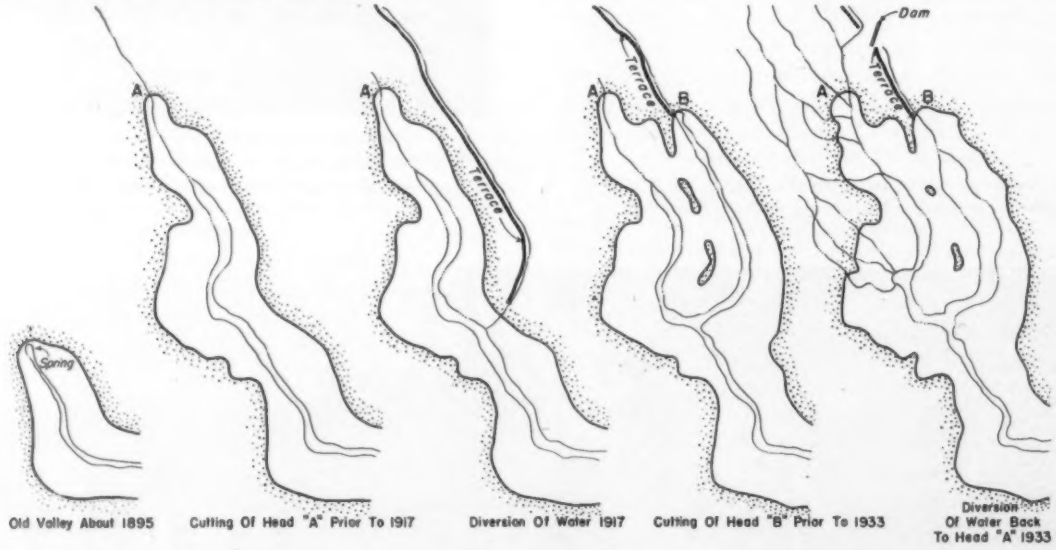
THE gully on the farm of R. H. Barry near Moore, Spartanburg County, S. C., is an excellent illustration of the way in which an intelligent farmer has successfully tackled the problem of erosion through "rotation of gully heads." A wooded valley in Appling soil, headed by a spring, was converted into a headward-cutting gully (designated as "Head A") as a result of erosion induced by cultivation. By 1917 gullying had become serious and the owner diverted the water away from the cutting head by means of a terrace to enter the main channel about 150 feet farther down. The new channel outlet was unprotected and the water started a new gully head (Head B) which migrated headward along the terrace channel. The older gully was set out to briars, climbing rose, and honeysuckle, and rubbish was thrown into the head. Assisted by caving of bermuda sod, the walls and head began to stabilize themselves.

In 1933 Head B had been cut to about the same length as Head A and was considered a hazard. In the interval of 16 years Head A had become so well stabilized that the farmer decided to plow out one side of the terrace leading to Head B, block the terrace drain, and divert the water back into Head A. Head B is now beginning to be stabilized by saplings, briars, and rose cuttings, and the walls are caving so that they will eventually form a slope on which vegetation can be established. Head A is showing slight effects from the new irritation but, by the time it gets to a hazardous stage, it is expected that Head B will be sufficiently stable to receive again the water which may be turned back into it.

In addition to the protection afforded by the rotation of heads, most of the fields draining into the gully are well protected by lespedeza alternated in broad strips with wheat. Where cotton is grown, an inter-row of

[1] The thesis presented in this paper was developed in conjunction with Dr. Maurice Donnelly in November 1936.

[2] Associate soil conservationist (Physiographic Research).



Alternate gully heads on a South Carolina farm. Head "A" at left is well vegetated and now receives the run-off from the farm, while head "B" at right is given time to grow protective vines and grasses. The gully head is surrounded by a pasture of Bermuda grass with cotton beyond the fence at the left and wheat after lespedeza in the field beyond the house.

oats is used as a winter cover. The whole farm has gentle slopes, the maximum not over 10 percent except in the old timbered valley through which the gully drains. Immediately adjacent to the gully is a Bermuda grass pasture, extending 100 to 200 feet back from the rim, which is quite effective in reducing and distributing the run-off from the cultivated fields.

Of Wide Application

A PROPOSED procedure for the application of the principle of rotation of gully heads to other areas might be as follows: If a multiple-head gully is surrounded by cultivated fields with terraces draining into the gully, all of the water from the major gully heads might be diverted into one or two of the less active or partially stabilized heads, now receiving very little run-off. Appropriate vegetation could then be started in the heads from which the water had been diverted. When the new drainage heads begin to show signs of excessive cutting the water could be returned to the original heads, which in the meantime had become sufficiently well stabilized to handle the run-off. Temporary structures might be employed at first in order to allow some of the treated heads to gain a good cover of vegetation. Later, when the vegetation in any of the drainage heads begins to fail, the water could be diverted to another head where the vegetation was well established. A strip of land adjacent to the gully should be planted to bermuda grass, lespedeza, or other suitable cover to disperse the run-off as much as possible before it entered the gully. A procedure such as this would permit the utilization of the principle of rotation of heads as a regular part of the farm management.

It is conceivable that the water might be diverted from all heads and drained over some intermediate point on the rim. This would develop a new head but as the area between tributary gullies is not likely to be utilized agriculturally, the use of the new head would allow all of those formerly active to become vegetated until one or more could carry the surplus water without serious erosion. If such a new head on the rim were not allowed to work back farther than those being treated, no additional land would need to be abandoned to the gully area. And after the initial period of revegetation it is probable that no new gully heads would be required. If no additional agricultural land were damaged by the establishing of

(Continued on p. 244)

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HIGHWAY ME

HIGHWAY MENACE has only one connotation to the average man, familiar as he is with the accidents and fatalities incident to traffic. But the term could legitimately be applied to the serious and widespread loss of soil which has been incident to highway construction and maintenance in many parts of the United States. Because the condition is not universal, while improper management of farmlands is more nearly so, the loss and destruction of agricultural soil through erosion is, as a rule, tacitly if not openly laid to the farm operator. Seldom are the authorities in charge of highway operations called to the bar of public opinion in this matter, particularly since there has been a marked improvement in the design of great arterial highways during the past decade.

ACTUALLY these arteries, in the average county, form but a small fraction of the total highway system. Assuming a county to be 40 miles square, crossed by two arterial routes, these will total 80 to 110 miles in length, as against about 3,000 miles of so-called "county laterals"; in other words a linear ratio of about 1 to 30 or 40. The former enjoy the supervision of well-organized Federal and State highway departments, often working together; the latter are dependent upon the attention they receive from county or township authorities, aided by county engineers who are often burdened with many other duties and who may not have the special training required for modern road maintenance.

FREQUENTLY these county laterals are doctored by local citizens working out their poll tax, often using powerful machinery, and commonly left pretty much to their own judgment.

IN many parts of the United States, particularly where there is an abundance of natural vegetation and little topographic relief, the consequences may not

(*Continued on p.232.*)

NOTE.—This article was prepared from materials supplied by Charles C. Smith and O. W. Hunn while temporarily employed by the Section of Climatic and Physiographic Research.

1. *Sharp ditches tend to cut laterally and vertically.*
2. *Sharp V-shaped ditches are the ideal of the average grading crew.*

6. Effects of many culverts s

MENACE

by

PAUL·B·SEARS

Collaborator of the Soil Conservation Service. Professor of Botany, University of Oklahoma.

vertically.
e average

3. In the loess areas of Mississippi, highways have dropped in some cases as much as 30 feet below the surrounding terrain.

4. Ten gullies to the mile is the average in one county on its lateral roads.

5. In one county of Oklahoma the average county lateral has sunk 2 feet since settlement.

many culverts suggest placer mining.

7. Broad, flat ditches covered with vegetation prevent cutting.

be serious. In northern Indiana and Ohio, for example, there are many roads which have been in continuous use for over a century without suffering much change of level or giving rise to serious erosion. The other extreme is to be found in the loess areas of Mississippi where highways have dropped in some cases as much as 30 feet below the surrounding terrain, the walls, because of the curious vertical structure of loess, often remaining nearly vertical, except where slumping and gullying have developed, as they frequently do.

IN one county of Oklahoma, for example, O. W. Hunn and Charles C. Smith have recently found that in the 40 years since settlement, the average county lateral has dropped about 2 feet, and is responsible for about 10 gullies to the mile. Similar conditions exist in adjoining counties. The tonnage of soil which has been thus lost is appalling.

ON the other hand, in comparable areas of Texas, a much older State, the damage may be considerably less. According to Hunn, this may be due to the fact that the roadways of Texas are based upon early trails, and hence upon topography. However, there are many examples of excellent highway drainage practices being employed in the State. The Oklahoma roads, on the other hand, are based upon the rectangular system of congressional townships and sections inaugurated in 1786, and subsequently employed, so far as possible, wherever new United States lands were opened to settlement.

THE development of this grid of section line roads, regardless of the course of topography, has had the effect of superposing upon the original drainage system an entirely new pattern. The removal of vegetation is in itself sufficient to establish a pathway for water; and where rainfall is inadequate to restore a vegetative cover promptly it is the more likely to be severe when it does occur. Moreover, the higher temperatures of the Southern States, favoring, as they seem to, the production of colloidal soil material through chemical weathering, are in themselves probably conducive to rapid erosion even where rainfall is favorable to quick revegetation. Thus, the contributory part played by roads in gully erosion is to be expected in the grassland States and in the Southern States generally, except where, as in parts of Texas, it has been checked by other factors.

IT must be noted, however, that under some conditions any kind of roadway, whether based upon old trails or a grid system, is a potential erosion menace. This is true in the southern Piedmont area, whose highways originated without reference to the congressional township plan.

IN practice, the first effect of altered drainage thrown into a new road is to roughen it by developing channels. This calls for reworking of the surface, of course. But with the powerful grading machinery now available, effort is not confined to smoothing the furrowed surface. Sharp ditches are cut at the sides, on the theory that they will get water off the surface as soon as possible. But any physiographer recognized a V-trench as a youthful drainage line, automatically inviting rapid cutting, both vertical and lateral. This in fact, is precisely what occurs in the majority of cases. Field observations made by Hunn and Smith, and by others as well indicate that where the ditches are relatively flat, and particularly where their vegetative cover is not disturbed, such cutting is reduced to a minimum.

QUITE as serious in its consequences, although less widespread, is the improper placement and design of culverts. Frequently these concentrate the flow and give it a drop which causes rapid cutting. In the worst cases the effect suggestss placer mining.

IT is not to be inferred from the preceding paragraphs that the problem is merely one of ordinary engineering technique. In the last analysis it is part of the broad general problem of adapting the landscape to a modern civilization. Fundamentally this is an ecological problem, and a very difficult, not to say challenging one. Needs and relative values must be determined, and a working balance established between man and his environment so that the present destruction of capital wealth can be stopped. In detail the problem is also one of ecology. The creation and mairntenance of a suitable plant cover which will minimize erosion and yet not impede necessary drainage calls for as intelligent understanding of vegetation and plant succession.

RECOMMENDATIONS for remedy will appear in forthcoming reports. In the meantime it has been found easy to interest chambers of commerce in

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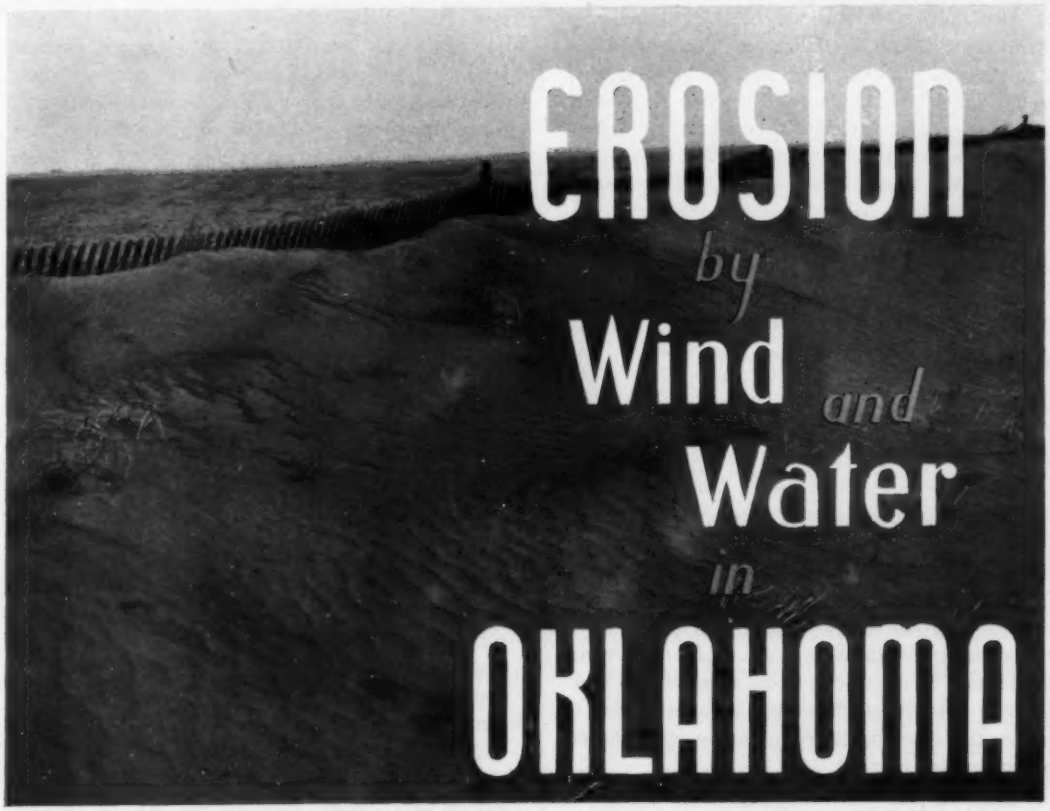


Gradually local drifting merged into the greater problem of dust and sand storms.

BY

ANGUS

MC DONALD [1]

THE RUSH of settlers to Oklahoma, which continued from the first opening in 1889 to the last in 1906, resulted in a rapid destruction of the native vegetation. Under natural conditions eastern Oklahoma was predominantly forest, while the west was grassland. Between these was a transition zone in which the boundaries of the two are shifting and ill-defined. Almost immediately after the removal of the vegetation, erosion in Oklahoma became critical. The gradual pecking by drops of water upon the cultivated soil, the local shifting of the sands by the wind, passed unnoticed in the beginning. Yet each segment of land presented in miniature a picture of the entire area at a later date and a warning of what may be expected after a period of exploitation.

Water erosion, in particular, escaped notice. The land was gradually whittled away; the changes, imperceptible at first, were discovered too late or ignored as unimportant. Even when erosion had reached a point where it could no longer be ignored, it did not receive the consideration that it merited. Land was still plentiful and when the soil from a hillside was washed away, the farmer cleared more land in the bottom or upland and abandoned his first field.

[1] Formerly Assistant Soil Conservationist (Erosion History), Section of Climatic and Physiographic Research.

Erosion appeared first in those areas which were put into cultivation earliest. Old Oklahoma was opened in 1889 and the Cherokee Outlet in 1893. Large parts of this area, especially in the east, were planted in wheat and corn. These regions were naturally the most attractive to the immigrants from humid lands, especially to those who had experienced disaster in the semiarid sections of Kansas and other States during the drought of the early nineties.

The Panhandle and western tier of counties were shielded from exploitation for a few years because of isolation and aridity. The rancher clung on as long as possible and, although dominated entirely by self-interest, convinced many that extreme western Oklahoma was not suitable to farming. But the fate of the extreme west was only delayed. As the more desirable portions were occupied, the homesteader pushed into the remaining territory. The settlement of the southwest (with the exception of Greer County, which had been settled earlier as a part of Texas) began with its opening in 1901. The years which remained before statehood witnessed the destruction of the free range. The rancher had come sharply into conflict with the farmer as each new area was opened. The result was always victory for the farmer and finally in 1906 the "Big Pasture" was opened and the range was no more. Not only were the newly plowed lands susceptible to erosion, but as the range became successively smaller, and overgrazing resulted.

Soil Blowing Begins

Although farms in the sandy areas suffered from water erosion at certain periods of the year due to the spasmodic rainfall, the problem of wind erosion with its more spectacular aspects, was readily noticed by those who occupied the land. Drifting of the soil, especially when it destroyed young plants, could not be ignored, and the unpleasant effects of sand and dust, rendered the farmers more alert to the problem.

Farmers in the west had long been familiar with dust storms by the time they first made their appearance in Oklahoma. Reference to sand and dust storms during unusually dry years are numerous in the files of farm papers. They were not usually localized and it is probable that the storms of Oklahoma during the early nineties had their inception in Kansas and farther north since they did not always coincide with unusually dry local conditions.

In its early stages sand drifting is quite distinct from sandstorms, although both are caused by lack of moisture, and the remedy for both lies in proper use of the soil. At first drifting was purely local and in consequence farmers at first tried to solve the problem locally. Their methods were varied, often complex, and based solely upon individual experience. But as the drifting became more widespread the problem became too large for individual concern. A farmer who had effectively practiced methods for controlling blowing found his crops buried in a sea of dust from neighboring fields. Almost imperceptibly local drifting merged into the greater problem of dust and sand storms.

Trial and Error

The erosion control practices employed by the more progressive farmers were based on their own experience and since most of this experience had been acquired in the more humid sections of the country, a period of trial and error preceded the development of control practices adapted to the new environment encounterd in Oklahoma. The first big problem of the farmer was to insure adequate moisture for crop growth. The solution or partial solution of this problem led to the westward extension of agriculture. Practices such as dry farming, introduced to insure adequate moisture for crops, increased the erosion by wind and water and new techniques were developed to combat the growing problem. In some areas it was necessary to abandon deep fall and winter plowing to check the blowing. In other areas listing supplanted plowing and on very "blowy" land the disk entirely replaced the lister and the turning plow. The harrow, which resulted in disaster in some places, proved beneficial under other circumstances. As early as 1904 it was recommended that the plains farmer turn back to grass, and in 1902 John Fields began his long crusade for Bermuda. Other cover crops were recommended and tested by individual farmers, and experiments were made on the restoration of humus to the soil.

Farmers who thought that they had found the solution to the erosion problem recorded their successes in the local farm journals. Others who adopted these practices wrote telling of their successes or failures. In this way erosion control measures were tested under a variety of environmental conditions and over a long period of years. Results proved that there was no universal method of meeting the problem; that the practices employed must be adapted to different climatic conditions and different soil types. This involves not only further controlled experimentation but also the determination of regional types of erosion processes.

In 1902 John Fields began his long crusade for the planting of Bermuda grass to control erosion.

In spite of the intelligent efforts of individual farmers erosion by wind and water swept over the State of Oklahoma. For the work of one progressive farmer there were careless methods of farming by the hundreds. The solutions of individual cases of erosion lose much of their significance when later the enterprising farmer is overwhelmed by erosion caused by his neighbor's neglect. The frequency of such occurrences indicates that soil erosion is a community problem which can be solved only by a land-use and land-conservation program which includes all of the farms rather than a few. But without the preliminary experiments of individual farmers the development of an adequate program of land-use could never be formulated.

ECOLOGICAL RELATIONSHIPS IN THE OKLAHOMA CLIMATIC RESEARCH CENTER

By J. E. Engleman [1]

THERE are perhaps few areas of comparable size more suitable for observing the reactions of plant life to climate, topography, and soils, than this which is included in the Kingfisher Climatic Project. Beginning with eastern Logan County, it extends 84 miles westward through Kingfisher and Blaine Counties and shows a range in elevation from less than 900 feet in eastern Logan County to more than 1,800 feet in western Blaine County. This increase in elevation is rather gradual until the escarpment known as the Gypsum Hills is reached. It rises 200 to 300 feet above the plains of southwestern Kingfisher and eastern Blaine Counties and roughly parallels the course of the North Canadian River. Another less abrupt rise southwest of the North Canadian River in western Blaine County results in the maximum elevation of the area. Three sand-choked rivers with broad, irregular belts of aeolian material along their north slopes flow in a generally southeast direction, the Cimarron River across Kingfisher and Logan Counties and the North

[1] Junior soil conservationist (Climatic Research), Section of Climatic and Physiographic Research; Oklahoma. Climatic Research Center.

and South Canadian Rivers across Blaine County. Average annual rainfall varies from about 25 inches on the west to about 35 inches on the eastern boundary.

The southeast third of Logan County lies within the Central Cross Timbers, a belt of Black Jack Oak (*Quercus marilandica Muench.*) and Post Oak (*Q. stellata Wang.*) which covers a large part of the sandstone hill region of central Oklahoma. The presence of ferns and other plants adapted to shade and abundant moisture lends an appearance of lushness not found over the rest of the area. Fingers of Black Jack Oak follow the aeolian belts of the rivers mentioned above from these Central Cross Timbers to quite a considerable distance northwest of the three counties, but the existence of woodland west of Logan County is probably made possible only by the relatively deep deposits of loose material. Where more clayey soils are found, only a few miles from the woodland, mixed prairie occurs; in Blaine County, although Black Jack Oak grows in nonaeolian sandy soil it does not form woodland. There is evidently little run-off of precipitation along the north slopes of the Cimarron and North Canadian Rivers in the western half of the area. Few drainage courses flow to the south, the dune sand absorbing most of the moisture that falls and retaining it in a form readily accessible to plants. An erosional remnant south of the Cimarron River and west of Kingfisher illustrates admirably the interaction of soils and climate. It consists of a central core of relatively deep dune sand on which Black Jack Oak woodland and tall grass prairie occur. As the depth of aeolian deposit decreases the tall grass proper gives way to mixed prairie, bunch grass etc., which in turn is supplanted by short grass on the soils of extremely tight texture.

Prairie Vegetation

IN the bad lands of the Gypsum Hills and extending eastward into the plains for varying distances the soils have a high alkaline content and a generally tight texture. Numerous "alkali spots" on which only salt grass (*Distichlis stricta Rydb.*) thrives, are found here. The vegetation is in general that of an arid region: mesquite (*Prosopis glandulosa Torr.*), prickly pear (*Opuntia camanchica Engelm.*), yucca (*Yucca glauca Nutt.*) and triple-awn grass (*Aristida spp.*) being the most obvious indicators. Though these drought-resisting forms persist into the hills proper they are there accompanied by many plants adapted to more stable soil conditions, some of which are unique to the locality as far as the area is concerned.

The presence of sand sage (*Artemisia filfolia Torr*). along the north slopes of the rivers is quite characteristic in northwestern Kingfisher and Blaine Counties and southern Blaine County. It also occurs along the slopes of some of the tributaries of the South Canadian River in western Blaine County. A form common to more arid regions, its occurrence adjacent to Jack Oak woodland in northwestern Kingfisher County is worthy of note.

Representative of State

IT would surely be not far wrong to say that tall-grass prairie prevails in the Logan County grasslands and that west of there the grassland types are determined by soil texture. Thus tall-grass prairie is found in Logan County and in western Blaine County but in the intervening portion the grasslands are most commonly of the mixed prairie (bunch-grass) type and not infrequently short grass, with tall grass occurring where the looseness of the soil forms a favorable environment.

In considering the area as a whole one may be struck by a similarity with the general character of the State. Both have more marked relief, lower elevations and more mesophytic vegetation to the eastward. Both have a wide variety of soil types and topography. The influence of comparatively uniform rainfall in the area is offset in many places by conditions of topography and soil which afford a range of plant forms somewhat comparable with that of the State.

Section Program

(Continued from p. 220)

drifting sands but on all types of eroded lands. The search presupposes an intimate knowledge of the processes of erosion and the natural methods of recovery in all climates and on all types of soil and bedrock. Holland grass came originally from the northwest coast of Europe. Kikuyu, another valuable soil binder, came from South Africa. Other plants successful in erosion control have been introduced from South America and Asia. A systematic study of foreign areas having climate and physiography similar to our eroded lands will enable us to capitalize on the experience acquired during a longer agricultural occupance.

Man, through his misuse of land, has accelerated erosion. The present problem is to accelerate its control proportionally. This can be accomplished only through intimate knowledge of erosion processes and the way in which recovery would proceed under normal conditions.

SAMPLING THE WEATHER AT THE OKLAHOMA CLIMATIC RESEARCH CENTER

By Leonard B. Corwin[1]

THE OKLAHOMA Climatic Research Center established by the Soil Conservation Service in cooperation with the United States Weather Bureau, has the distinction of being the most comprehensive undertaking ever attempted for the study of microclimatology and its application to the problems of soil conservation. In an area 30 by 80 miles in extent, including Blaine, Kingfisher, and Logan Counties, 200 fully equipped weather stations have been established. All weather instruments are read simultaneously and at short intervals. In this way it has been possible to trace individual storms as they cross the project area, to observe their behavior, determine their water contribution to each part and to the entire area, and to classify them according to their morphology.

Project Organization

THE detail required in order to develop the concepts presented by C. W. Thornthwaite in his article entitled "Life History of Rainstorms" (Geographical Review, vol. 27, no. 1, January 1937, pp. 92–111)[2] is apparent only when the organization of the project is considered. All of the workers, with the exception of a small scientific and administrative staff, have been supplied by the W. P. A. The weather stations are spaced on an average of 3 miles apart and the observers prepare hourly reports on temperature, wind direction and velocity, humidity, dust, cloudiness, fog, and thunderstorms activity. Precipitation is recorded at 15-minute intervals from 7 a. m. to 7 p. m. That which falls during the night is accumulated and measured at 7 a. m. the next morning. Since the installation of 100 self-recording rain gages on the project, rainfall maps for each half-hour interval during the night have been prepared. These reports are mailed daily to the office at Kingfisher, Okla. If a day is clear and without rainfall, cloud, dust, fog, or frost, about 13,600 individual weather readings are received. If the day is continuously rainy, 9,800 additional readings are required and other miscellaneous observations may add another 3,000, bringing the total number of items to be considered to the notable figure of 26,400 for a single rainy day.

In addition, to transpose these observations, the office staff must compute relative humidity from the readings of the wet- and dry-bulb thermometers, requiring a total of 2,600 computations daily. The wind velocity is recorded by observers in "buzzes" per 2-minute interval. To change this to miles per hour another 2,600 computations being required. Similarly, the rainfall is measured in cubic centimeters in a glass graduate and must be converted into inches of precipitation. The latter may involve as many as 9,800 additional computations for one day.

Climatic Mapping

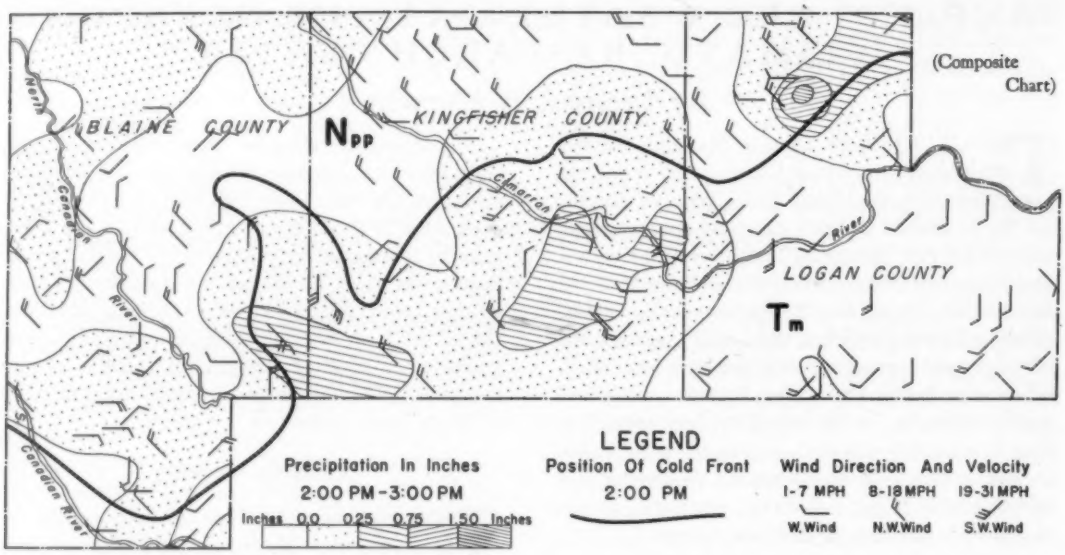
THE map was selected as the best method for presenting this detailed meteorological information. An average of 120 maps are required for each day, and for a rainy day over 200 are prepared. The maps serve the dual purpose of presenting the information graphically and checking upon the accuracy of the observers. One person reads the data from the observer's records and another plots them on maps. When all the necessary information has been transferred to the maps, lines or isorhythms are drawn connecting points which have equal values of temperature, rainfall, cloudiness, or wind velocity. The direction of the wind is shown by arrows flying with the wind. If one station records values abnormally higher or lower than those surrounding it, it is checked with the observer's report to see that no error has been made in the plotting. If the observer was at fault an "X" is placed after the incorrect value on both the map and the observer's record, and the observation is disregarded in drawing the isorhythms. Similarly, different types of maps are checked against each other.

All errors are reported back to the observers. When too many errors accumulate for one observer or if he continues to repeat the same type of mistake after it has been called to his attention, sufficient justification exists for removing his station. The result has been an unusually high degree of accuracy in the observations as a whole. This is absolutely essential to the success of the project.

THE microclimatic maps are supplemented by four daily maps, prepared for 6-hour intervals, upon which are recorded approximately 50 complete meteorologic observations made by United States

[1] Junior Soil Conservationist (Climatic Research) in charge of Oklahoma Climatic Research Center.

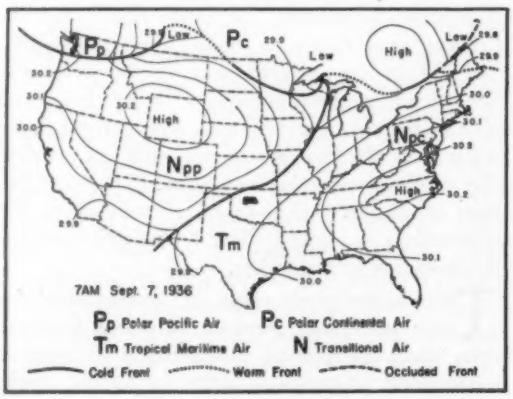
[2] Reviewed by Katherine C. Hafstad, Soil Conservation, vol. 2, no. 7, January 1937.



Weather Bureau stations and intermediate airways weather-reporting stations located either in Oklahoma or the States bordering it. In addition, an analysis of the weather map for the entire United States furnishes a still broader view of the meteorologic situation affecting the project area.

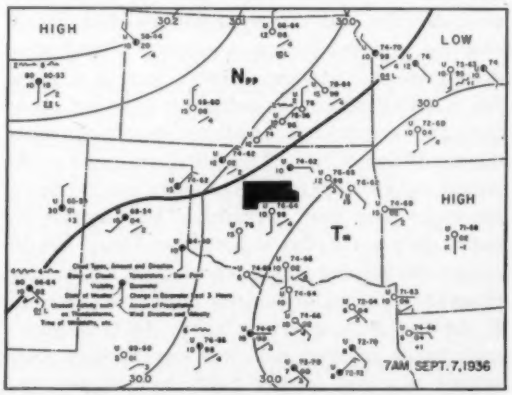
Storm Analysis

Examples of the three types of maps are shown in the accompanying illustrations. The first is a synoptic picture of the weather situation for the United States at 7 a. m. central standard time on September 7, 1936. The boundaries between the different air bodies have been indicated and the air masses have been appropriately labeled according to whether their source lay over a Polar Maritime (Pm), Polar Continental (Pc), or



Tropical Maritime (Tm) region. The significant feature of this map in relation to the Climatic Center is the frontal boundary which lay to the north of the area. This boundary indicates the advance of a Polar Maritime air body into an air mass of Tropical Maritime origin.

The second illustration shows a more detailed picture of the same meteorologic situation at the same time. The accompanying diagram indicates the general grouping and character of the information plotted. The various observations are quite complete. It is to



be noted that nowhere among this network of weather stations is rainfall occurring.

A composite chart showing a part of the information obtained from the observations of the Climatic

(Continued on p. 244)

THE PROBLEM OF SOIL EROSION IN ANTE-BELLUM VIRGINIA

By A. R. Hall[1]

Washington, a pioneer soil conservationist, experimented in erosion control at Mount Vernon.

PATRICK HENRY is said to have remarked upon one occasion soon after the Revolution that "since the achievement of our independence, he is the greatest patriot who stops the most gullies." This statement indicates that soil erosion as induced by cultivation was becoming a problem of considerable magnitude at a comparatively early period. What other written evidence do we have to date the beginnings or progress of erosion in Virginia?

We are perhaps safe in saying that soil washing in the interfluvial ridges of tidewater Virginia and in the Piedmont became serious practically as soon as land was brought into cultivation. However, the first generation of farmers and planters had little or nothing to say about it. Little concern was felt about the destruction of a commodity as plentiful as land. Tobacco continued to be "hilled up" with the hoe. Corn land continued to be plowed in straight lines, regardless of the slope, so that furrows were often laid directly up and down a hill. Only with the growing scarcity of virgin tobacco land and the coming of the prolonged agricultural depression at the end of the eighteenth century did the planters begin to think and write about the seriousness of their erosion problem. From this period dates the most abundant documentary evidence of early soil wastage in Virginia.

An Englishman at Mount Vernon

The Father of his Country was one of the first to attempt to prevent the depletion of that country's resources. As early as 1769 he was conducting experiments in plowing and harrowing at Mount Vernon to determine which method would do most to preserve the land. Since long absence from the estate prevented systematic efforts at good farming, Washington thought seriously, a quarter of a century later, of letting out most of his land to English tenants. In a sales letter written with this in view he said—

> A husbandman's wish would not lay the farms more level than they are; and yet some of the fields, but to no great degree, are washed into gullies, from which all of them have not as yet been recovered.

Richard Parkinson, an Englishman who was attracted to Mount Vernon by Washington's offer, found that this was all too true, not only of the estate itself but of the adjacent land along the Potomac. Later, Parkinson settled upon a farm near Baltimore where he had some disheartening experiences with this (to him) novel phenomenon of soil wastage. On land that had been pulverized as he would have done English land he found that:

> . . . the whole of the soil [moved], for an acre together, when a heavy rain fell, from the current in some places cutting gullies, and carrying part of the manure away; and the soil seemed to press in or slip after it.

Parkinson at length concluded that:

> Upon the whole, America appears to me to be a most proper place for the use to which it was first appropriated, namely the reception of convicts.

As we might expect, most of the complaints against erosion came from the Piedmont. An English officer held captive by the Revolutionary forces at Charlottesville and Richmond noted that soil washing in the

(*Continued on p. 243*)

[1] Assistant soil conservationist (Erosion History).

SLOPE FACTORS IN SOIL EROSION

With Illustrations from the Kentucky Karst

By H. Bates Brown, Jr.[1]

SLOPE has long been recognized as one of the major factors in determining erosion potential. In an attempt to define erosion hazard in relation to slope, the Soil Conservation Service has divided all slopes into four groups and has made major land-use recommendations accordingly. These classes, designated by the symbols A, B, C, and D, are all based on the degree of slope. Slopes of group A, the gentlest, are expected to experience a minimum of erosion under normal conditions of tillage. D slopes are the steepest and it is recommended that they be taken out of cultivation. The B and C groups, intermediate in slope, are regarded as needing erosion control measures if cultivated.

While the original concept of four slope classes has been maintained, it has been modified locally. Subdivision of the major groups have been made in different regions to indicate more specific land-use recommendations. Likewise there has been a constant refinement in the definitions of the various slope classes. For example, in South Carolina group A includes slopes up to 3 percent, but in some of the more northern States the limit is extended to 5 percent.

Although slope classification according to the degree of slope has the advantage of being on a workable quantitative basis, it has the disadvantage of leaving out of consideration certain other recognized qualities of slope which may be even more significant than gradient. One of the most obvious hazards of slope that is not apparent in an instrumental determination of the degree of slope is its length. In the case of a long slope, serious erosion often occurs near the base where concentration of water is naturally greatest. An A slope lying at the foot of a long B slope may be the more susceptible to erosion because of the increase in volume of water coming off the long slope above. The construction of terraces may alleviate the condition to some extent by diverting the surface run-off from the lower lying lands, but by further lengthening the course which the water must take before reaching the base level, it may lead to a greater concentration of run-off and thus increase the hazard of gullying.

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NOTE.—*The problems of soil erosion in the Kentucky karst are being more completely treated in a forthcoming manuscript by S. N. Dicken and the writer.*

Direction of Slope

IN some regions the direction which a slope faces may be more significant from the erosion standpoint than is the degree with which it declines. In parts of Kentucky and Tennessee very striking contrasts in the landscape may be observed, depending on the direction toward which the land slopes. In the hilly "knob" country, underlain by flat-lying beds of limestone, south-facing slopes are so denuded of their soil cover that they consist of virtually nothing but bare limestone outcrops. In striking contrast are the adjacent north-facing slopes which are mantled with deep soils even though the degree of slope is commonly

The effect of exposure on erosion. The pictures on these two pages show the opposite sides of the same knob. That on the left is of the south slope; that on the right the north slope. The soil has been almost completely removed on the south side, sloping at 23 percent; whereas, the north side, although much steeper (33 percent), retains a good deep soil which is being tilled with a minimum of erosion loss. The corn in the background is the best on the farm, which includes a considerable amount of relatively level land. The few tobacco plants appearing in the foreground have been left to make seed, mute testimony as to what this farmer thinks of the tobacco grown on this steep but productive hillside. The bedrock is flat-lying limestone; the pictures were taken at about the same elevation on the two sides of the knob; thus, the parent soil material is the same.

greater. Under virgin conditions the vegetation of the southerly slopes is a sparse growth of red cedar, scrub oak, and bluestem grass, growing on patches of thin soil which remain in fissures between ledges and boulders of limestone. In contrast, dense oak-hickory forests cover northern exposures. Steep northerly slopes are often cleared and cultivated while gentler southward-facing slopes remain in their virgin denuded condition, the soil being too thin to warrant clearing.

Eastward- and westward-facing slopes show a similar contrast but to a lesser degree. Eastward slopes resemble those facing south, while westward and northward slopes are comparable. The slopes listed in order of increasing erosion hazard would be north (least denuded), west, east, and south.

Effects of Exposure

THE effect of exposure on erosion appears to be especially significant in those parts of the country which experience a great number of alternations in freeze and thaw in the course of the year and along the borders of those regions which are covered with a snow blanket for a considerable length of time. In such places, northward-facing slopes, receiving sunlight at a lesser degree of incidence and for a shorter length of time, are protected during long winter periods by a continuous cover of snow or frozen soil. The relatively sunny southward slopes are thawed out more of the time and subject to the erosive action of running water and to other denudational processes accompanying thaw. On many days when the northward slopes remain frozen the southward slopes will thaw out in the daytime under the more direct rays of the sun only to freeze again at night. Consequently, the heaving of soil particles by growing ice crystals is repeated more often on southward slopes. The frequent heaving not only prepares the soil for ready removal by running water but is significant in aiding the gradual downhill creep. The more denuded soil and the greater evaporation on the sunny southern exposures are conditions unfavorable for vegetative growth. The reduced vegetative cover on southward slopes creates an additional erosion hazard.

More rapid erosion on southward-facing slopes is a natural phenomenon—one that cannot be controlled by man. That advanced erosion on these slopes has been the condition for countless ages is attested by the fact that they are usually gentler than northerly slopes. They have been gradually worn down to a gradient less than that of the other slopes.

The effect of exposure on the steep limestone hills of Kentucky and Tennessee becomes striking and easily recognized because of the abrupt contact between the soil and rock. The loose soil lying directly on the solid limestone base is very easily swept off. On southern exposures where soil removal processes are most active, the bleached white limestone outcrops and the totally different vegetation aid the observer in detecting the greater erosion. The strikingly contrasted conditions of the limestone slopes serve to emphasize the hazard to southward-facing slopes in

other regions where the process may be active but less noticeable.

It is to be assumed that when erosion is accelerated, as by cultivation, the natural process will work with greater force. That southward slopes are in greater danger than those that face the north, even though the southward slopes may have less gradient, is indicated by the Kentucky case. Many southward-facing hillsides with a slope of 25 percent or less have lost almost their entire soil cover and the bed rock is exposed. On the other hand, northerly slopes of 35 percent retain a good soil, several feet thick, above the same type of bed rock. Intelligent farmers have demonstrated that with conservative management this steeply sloping north land can be tilled with a minimum of erosion loss (see illustration). Their methods consist of plowing on the contour, using rotations to return organic matter to the soil periodically, and plugging every incipient gully that may appear.

Another hazardous quality of slope, which is not apparent in a statement of average gradient, is the form of the profile. Convex slopes are much more susceptible to erosion than are the concave. In the case of the convex profile the steepest gradient occurs near the base of the slope, which, as already pointed out, is particularly susceptible to erosion. Thus, erosion hazards are augmented. Convex slopes are especially susceptible to deep gullying, for that form of surface is directly opposed to the parabolic curve which the course of all streams, including those flowing in gullies, must reach before becoming graded and permanently stabilized.

The position of the land with respect to base level, whether the land is sloping or not, must also be considered in evaluating the erosion potential. Kentucky again furnishes an extreme example for this point. In the karst lands, underlain by thick beds of pure limestone, there is a notable scarcity of surface streams, the major drainage being underground. Solution in the limestones is so pronounced that underground channels have been cut out by dissolution and have become occupied by flowing streams. Surface run-off is supplied to the underground streams through numerous sinkhole openings. In this condition the soil material, which is simply a residue from solution of the upper limestone surface, lies perched, as it were, well above the base of wastage which has been established by the underground streams. Under natural conditions the soil apparently maintains itself in this precarious position, but when this delicate equilibrium is disturbed, as by an abnormal concentration of run-off, gullies form and rapidly cut down to the underground base of denudation.

The karst furnishes an excellent example of another hazard particularly significant from the standpoint of culturally accelerated erosion. Although it has the appearance of being a relatively flat country, it is made up of innumerable short slopes surrounding small depressions, commonly called sinkholes or basins. In planting row crops this is particularly significant. The great number, small size, and irregular distribution of basins limits the practicability of such soil-conserving measures as contour plowing, terracing, and strip cropping. Because of the short slopes the farmers are frequently forced to run their furrows without regard to topography. With this tillage practice the rows run on the contour in some places but at right angles to the contour in others. Rills and eventually gullies rapidly develop where the furrows run downhill as they cross small basins.

The Flood Hazard

Culturally accelerated erosion in the land of sinkholes has introduced another farming hazard—flooding. The most fertile soil is to be found in the basins inasmuch as the basin soil is mostly an accumulation of topsoil washed down from the surrounding ridges. But crop success cannot be depended upon because of the flood hazard. The basins, being clogged sinkholes, suffer poor drainage as the natural sinkhole drainage has been disturbed. After heavy rains ponds frequently form. If the water remains on the surface many days, as it does during wet years, crops are ruined.

Although the factors mentioned in this article are especially applicable to limestone lands, those in Kentucky in particular, the same factors have a significance of varying importance in other regions. Indications that southward-facing slopes are especially susceptible to erosion have been observed in such widely separated sections of the country as South Carolina, New Jersey, Idaho, and California. The matter of the susceptibility of convex slopes, common to many regions, is closely related to the principles of base level—a consideration of world-wide significance. Where all other slope factors are constant erosion hazards may be assumed to increase with gradient. But other factors are never constant and slope is but one of many varying factors in erosion. Consequently, intelligent land planning and the application of workable erosion control practices in any locality requires an intimate knowledge of the prevailing conditions.

Erosion in Ante-Bellum Virginia

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upper Piedmont caused the James River to look like a "torrent of blood" during the freshets of 1779. A certain Dr. William Meriwether informs us that the insidious process of sheet wash had done widespread damage in Amelia county by 1790. By that date the gray surface soil of much of the county had been swept away, leaving the subsoil of hard, tenacious red clay exposed. A Prince Edward County farmer writing at a later time, estimated that very little hilly land cleared for more than 20 or 30 years was of any value because of the prevalence of soil washing. The inroads of erosion in the counties just east of the Blue Ridge, notably on soils of the Davidson series (the "red lands"), was very disquieting to early Virginians. This was regarded as one of the best agricultural areas of the State, yet one observer spoke of it as having been washed and gullied and as having presented the impression of nakedness at the end of the eighteenth century. Speaking of the area around Monticello, Thomas Jefferson complained that "fields were no sooner cleared than washed." James Madison, who lived in this same region, put the matter a little more conservatively, but none the less strikingly when he declared that without some soil-saving methods of cultivation the ownership of "red lands" was little more than a lease for years.

Early Agriculturists Concerned

In the hilly parts of the State erosion as induced by cultivation had its counterpart in the overwashing of valuable lowlands and the silting of stream channels, especially in the tidewater region. By 1813 John Taylor, of Caroline County, was calling this fact to the attention of the country.

> The disaster [he said] is not terminated by the destruction of the soil, the impoverishment of individuals, and transmission of a curse to futurity. Navigation itself is becoming its victim, and in many parts of the United States, our agriculture has arrived to the insurpassable state of imperfection, of applying its best soil to the removal of the worst farther from market.

Thomas Moore, of Maryland, writing in 1801, was one of the first to attempt to describe in detail the way in which agricultural practices caused soil erosion. He contended that the customary practice of plowing to a depth no greater than 4 inches was the cause of most erosion. Moore thought that, as a result of shallow plowings on southern fields the surface of the soil had become, by 1801, the whole depth of plowing lower than when first cultivated.

> What further proofs need we [he asked], to convince us that the practice of agriculture, particularly in the Southern States, is miserably defective, than the deserted old fields that so frequently present their disgusting surfaces from Susquehanna to Georgia?
>
> * * * * * * * * that this is a necessary consequence of *shallow ploughing* on lands that are in any degree hilly, in this climate, I trust has been satisfactorily proved.

Control Practices

While the urgency of the erosion question was gaining widespread recognition, forward looking agriculturists set out to "do something about it." Deeper plowing, the adoption of systematic rotations, the growing of cover crops, and the reduction of acreages in clean-tilled crops were advocated and practiced by a good many farmers. The practices of contour plowing, hillside ditching, and terracing were introduced in Virginia during the first half of the nineteenth century. Nevertheless, if these were good beginnings they were only beginnings. On the eve of the Civil War much still remained to be accomplished, as the two following quotations, dated 1856, indicate. One observer complained that Virginia was "bleeding from a thousand wounds inflicted by improvident husbandry" and that "we behold everywhere around us stunted vegetation, scanty crops, poverty of soil, and innumerable gullies and galds." After quoting John Taylor's passage regarding the silting of streams, another agricultural reformer lamented that:

> Nothing has yet been done to wipe from our agriculture the reproach of [Taylor]. The alluvial treasure, annually washed from our forests and badly cultivated soils, and floated down our rivers, continues to serve no other purpose but to obstruct our navigation and poison our atmosphere. Not one scientific effort has been made to arrest it in its progress to tidewater, and none to appropriate it below.

Thus, our ancestors found, just as we of today are finding, that the problem of erosion was not to be solved in a day.

Highway Menace

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this aspect of erosion; and as a start which will involve no special legislation, it is suggested that such agencies in key communities bring the matter to the attention of county commissioners and engineers. With a degree of intelligent supervision of road-working crews much of the damage can be arrested. And a few counties would serve as demonstration projects, thus arousing the interest of authorities elsewhere.

BOOK REVIEWS AND ABSTRACTS

By Phoebe O'Neall Faris

ESSAYS IN GEOBOTANY. Edited by T. H. Goodspeed. Berkeley, Calif., 1936.

This volume, published in honor of the scientific achievements of William Albert Setchell, includes a group of papers assembled with the idea of presenting a unified study of plant associations and rate of plant migration as related to climate and soil moisture. With the assumption that an understanding of the paleontologic record of a region, as well as of the living plants, forms the basis for any complete comprehension of modern vegetation, the article on succession and distribution of Cenozoic floras around the northern Pacific basin by Chaney, occupies a place well toward the front of the book. Following this Frederic E. Clements presents an extensive discussion of the origin of the desert climax and climate in North America. The objects of the paper are to explain the distribution of the typical dominant of the desert climax, *Larrea tridentata*, and its associates over an area much wider than that in which they are climax in the southwestern part of the United States, and their rapid spread in the wake of overgrazing and disturbances by man and rodents. In assembling his evidence, the author proceeds from the relicts which are still present in the desert, are few in the climax itself, and more frequent near the mountains, through the "transads" to and including the species that occur in the desert and on the side of it. Attention is given also to the changes that have taken place farther away in the grassland without transforming it into desert.

As background for the evidence derived from the migration of the desert climax in the Southwest and the evolution of endemics, the author presents an evaluation of fossil plants from Miocene to Pleistocene and associated fossil animals.

In a geographic study of the strand and dune flora of the Pacific coast of North America, William S. Cooper presents results of a general survey of plant species inhabiting the actual strand and areas of moving sand and species which occupy the surfaces of stabilized dune. Summarizing the flora discovered, the author states that "* * * we find first, a group of 26 species definitely derived from stock of the local hinterland, representing either genera confined to the region or local sections within widespread genera. This group includes one-third of the species of strand and moving dunes and practically all those of stabilized dunes. The genera represented are mainly characteristic of arid and semiarid habitats. Of the remaining 17 species, 14 (all of strand and moving dunes) are of subarctic or north temperate origin. * * * Three species (2 of shifting, 1 of stabilized dunes) are derived from the subtropics and South America."

Sampling the Weather

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Center comprises the third illustration. Here the precipitation pattern observed from 2 to 3 p. m. (determined by adding the amounts which fell during the four 15-minute intervals), is superimposed upon a wind direction and velocity chart of observations taken at 2 p. m. The frontal boundaries between the polar and tropical air bodies are indicated by the heavy continuous line. The complex character of the boundary is revealed only in this highly detailed analysis of the Oklahoma Climatic Research Center and it has been shown by Thornthwaite that these sinuate complexities bear a genetic relationship to rainstorm morphology. Actually, within a 2-hour period, approximately 5,000,000 tons of water were poured upon an area of 100 square miles in northwestern Logan County as a result of this atmospheric configuration.

The significant results that have already been obtained from the Oklahoma project regarding the characteristics of individual rainstorms and their direct bearing upon soil erosion and flood hazards has led to the establishment of a similar climatic research project in the Muskingum watershed in Ohio. Here a battery of 500 weather stations distributed over the 8,000 square mile watershed will be of great importance in comparing the behavior and character of storms in two entirely different climatic provinces. But of even greater significance will be the liaison that will exist between this climatic study and the hydrologic investigations already in operation in the Muskingum area. For the first time detailed data will be available for all phases of the hydrologic cycle. Fourteen flood-control dams and numerous stream-gaging stations are maintained in the Muskingum conservancy district, and the results of these investigations will be correlated with the soil-conservation climatic study. The two associated types of study should lead to a better understanding of the critical conditions that produce floods.

Rotation of Gully Heads

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new cutting heads, the end gained would fully justify such procedure.

The principle of rotation of heads would not be applicable to all gullies. It would require careful consideration of soil, climate, vegetation, crops, and slope. Physiographic studies of the process of gully cutting under different environmental conditions and agricultural systems, however, should make possible wider use of the practice of rotating gully heads to control erosion—a practice which has proved effective where tested and one which involves a minimum of expense to the farmer.

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